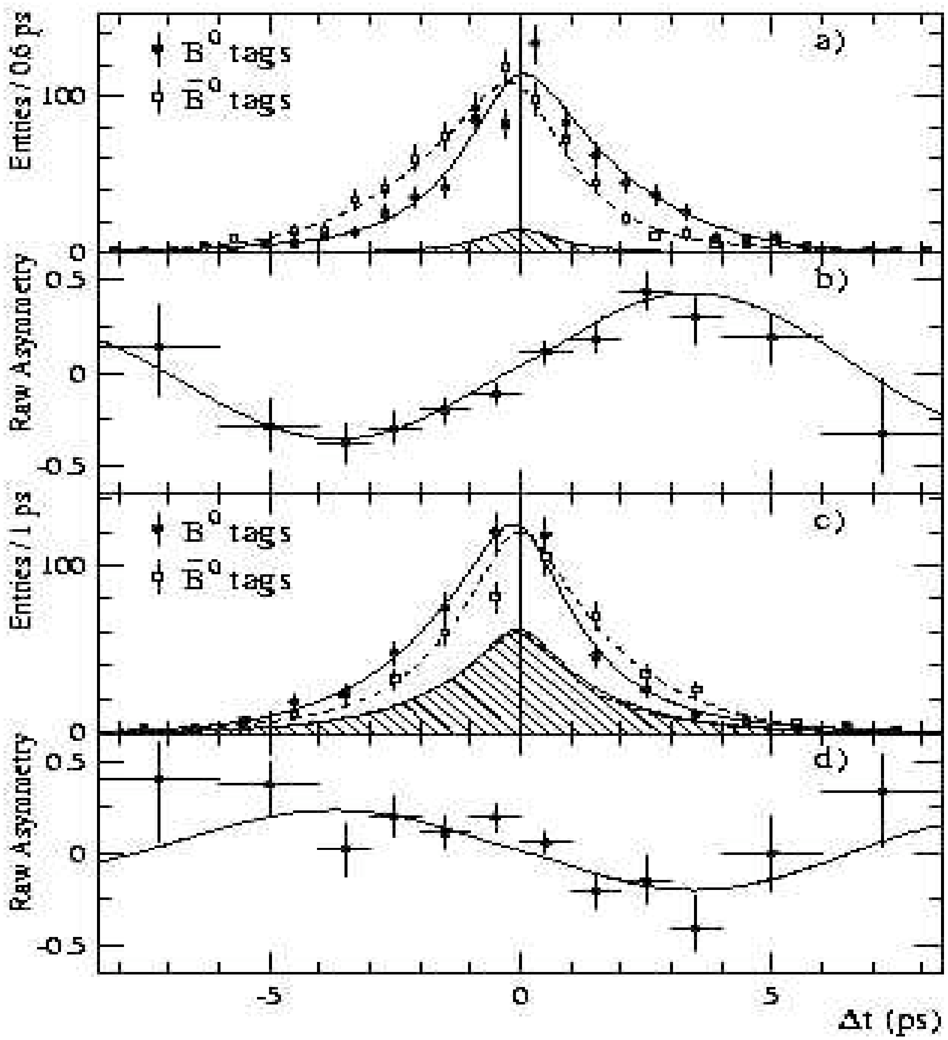
New Physics and the Future of B Physics

J. Hewett

CP Violation in the B System is Established



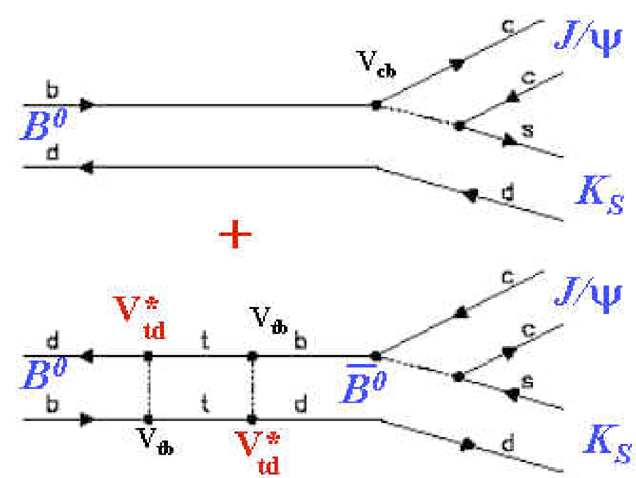
Babar 81 fb^{-1}

Charmonium Modes:

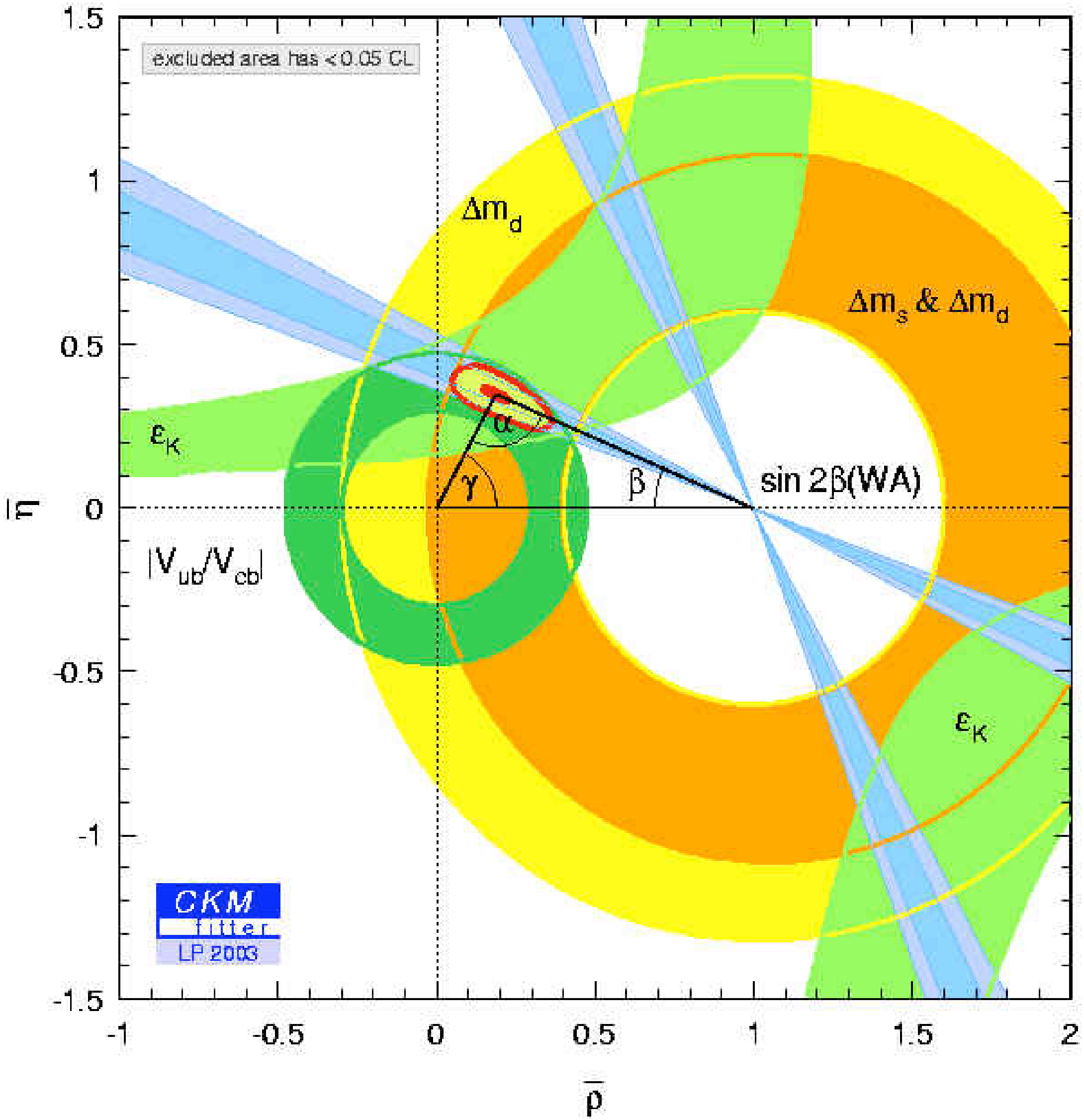
$\sin 2\beta = 0.734 \pm 0.055$

7% Precision!!

Measures Phase in B Mixing



All Data are Consistent (so far…)



95% CL Ranges:

$\bar{\rho}$ = 0.071 – 0.332
$\bar{\eta}$ = 0.259 – 0.419

The SM can explain magnitude of CP violation observed in the K and B systems

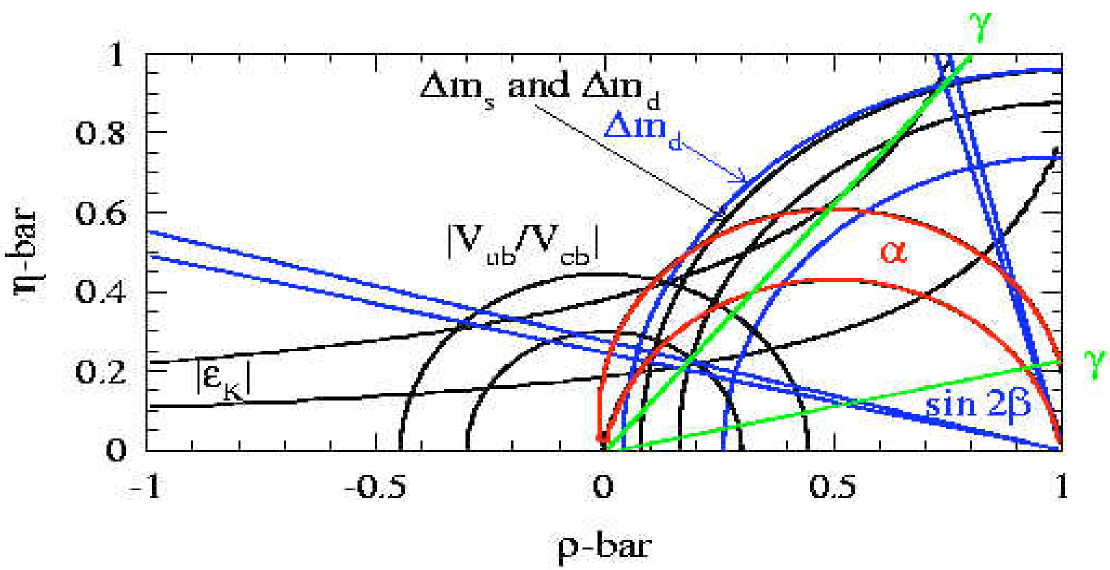
(Charmonium Modes)

Next Steps:

- **Accumulate ~500 fb^{-1} (1 ab^{-1} ?) by 2008-2010 at e^+e^- B-Factories**
- **Observe B_s Mixing at Tevatron**

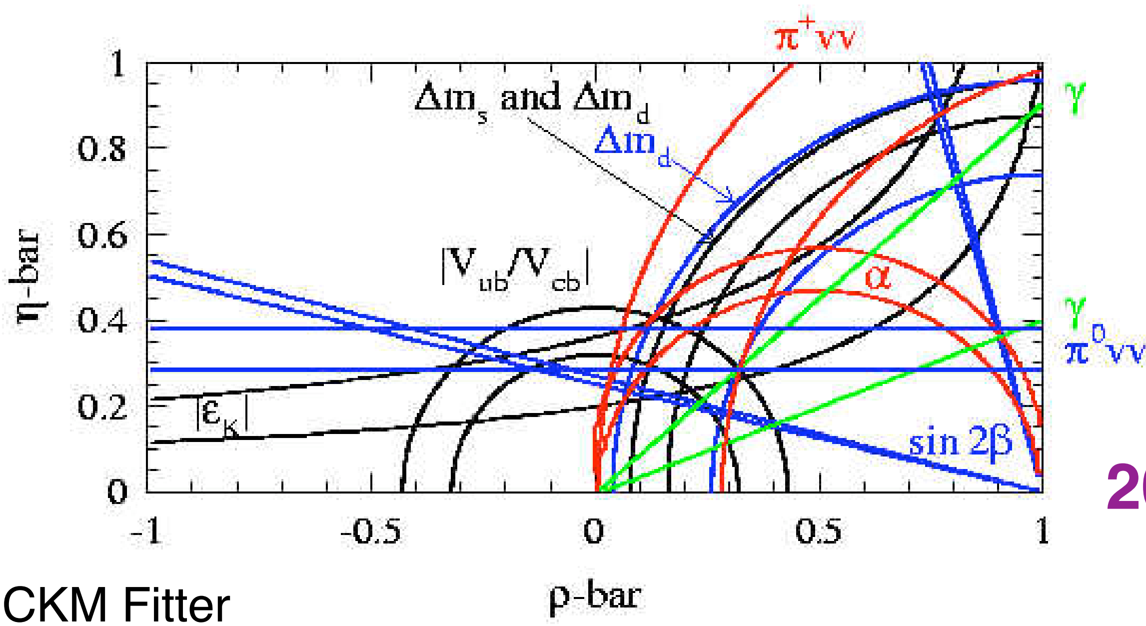
- **Continue to improve precision of measurements**
- **Observe new modes**
- **Try to open window to New Physics!**

The Future Picture (?)



2005

Only sin 2 is measured precisely!



Hadronic Uncertainties are too large for Ultra-Precision Tests.

2010

CKM Fitter

Future Steps: BTeV/LHCb + SuperB

Hadron and e^+e^- machines are Complementary for B-Physics as well as at high energies!

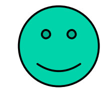
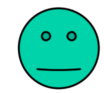
Feature	Quantity	Mode	2 x10^{35}	10^{36}	LHCb/BTeV
Side	V_{ub}	$B \to (\pi, \rho, X_u)\, l \nu$	★★	★★	-----
Angles	β (vs.ref.)	$B \to \phi K_S$	★★	★★★	★★
	α_{eff}	$B \to \pi^+ \pi^-$	★	★★	★
	α	$B^0 \to \pi^0 \pi^0$	★	★★	-----
	α	$B^0 \to \rho \pi$	★	★★	★★★
	~0	$B_S \to (J/\psi)\, \eta^{(\prime)}$	-----	------	★★★
	γ	$B_{(S)} \to D_{(S)} K$	★★	★★★	★★
Rare Decays	$C_{7,8,9,10}$	$B \to K^* l^+ l^-$	★	★★	★★★
	sign(C_7)	$A_{FB}(B \to K^* l^+ l^-)$	-----	★	★★
	Im($C_7 C_i^*$)	$A_{CP}(B \to K^* \gamma)$	★★	★★★	★★

+ B_s Mixing @ BTeV/LHCb

SLAC Scenarios Study

Context for Next Generation of Heavy Quark Experiments

LHC DiscoveryPossibilities:

- Plethora of New Particles/Interactions 
- Single SM-like Higgs 
- Strong gauge boson Scattering
- Nothing 

Are we interested in Heavy Flavor Physics in 2010?

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The SM leaves too many questions unanswered:

- The hierarchy problem
- The flavor problem
- The strong CP problem
- Baryogenesis
- Neutrino Masses
- How is gravity incorporated

⇒ We believe New Physics exists!!

Hierarchy Problem suggests $\Lambda_{NP} \sim 4\pi M_W \sim 1$ TeV

TeV scale can be probed in heavy quark sector with ultra-precise data.

Are we interested in Heavy Flavor Physics in 2010?

Yes ! Yes !

The SM leaves too many questions unanswered:

- The hierarchy problem
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Flavor Sector Questions!

$\Rightarrow$ We believe New Physics exists!!

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Heavy Flavor Physics in the LHC Era

- **LHC Discovers New Physics:**
  - $\square_{NP}$ Determined by ATLAS/CMS
  - Heavy Flavor exp’ts probe flavor violation associated with New Physics – measure the new flavor parameters

- **LHC Discovers Nothing/SM Higgs**
  - Heavy Flavors confirm SM predictions with ultra-precision

In either case, B-Factories play an important role

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B-Factories Determine Flavor Structure of New Physics

- **LHC Discovers Nothing/SM Higgs**
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In either case, need to improve theoretical accuracy:
Heavy flavor theory must become as precise as experiment!

Pictorial Example:

New Physics Parameter Space

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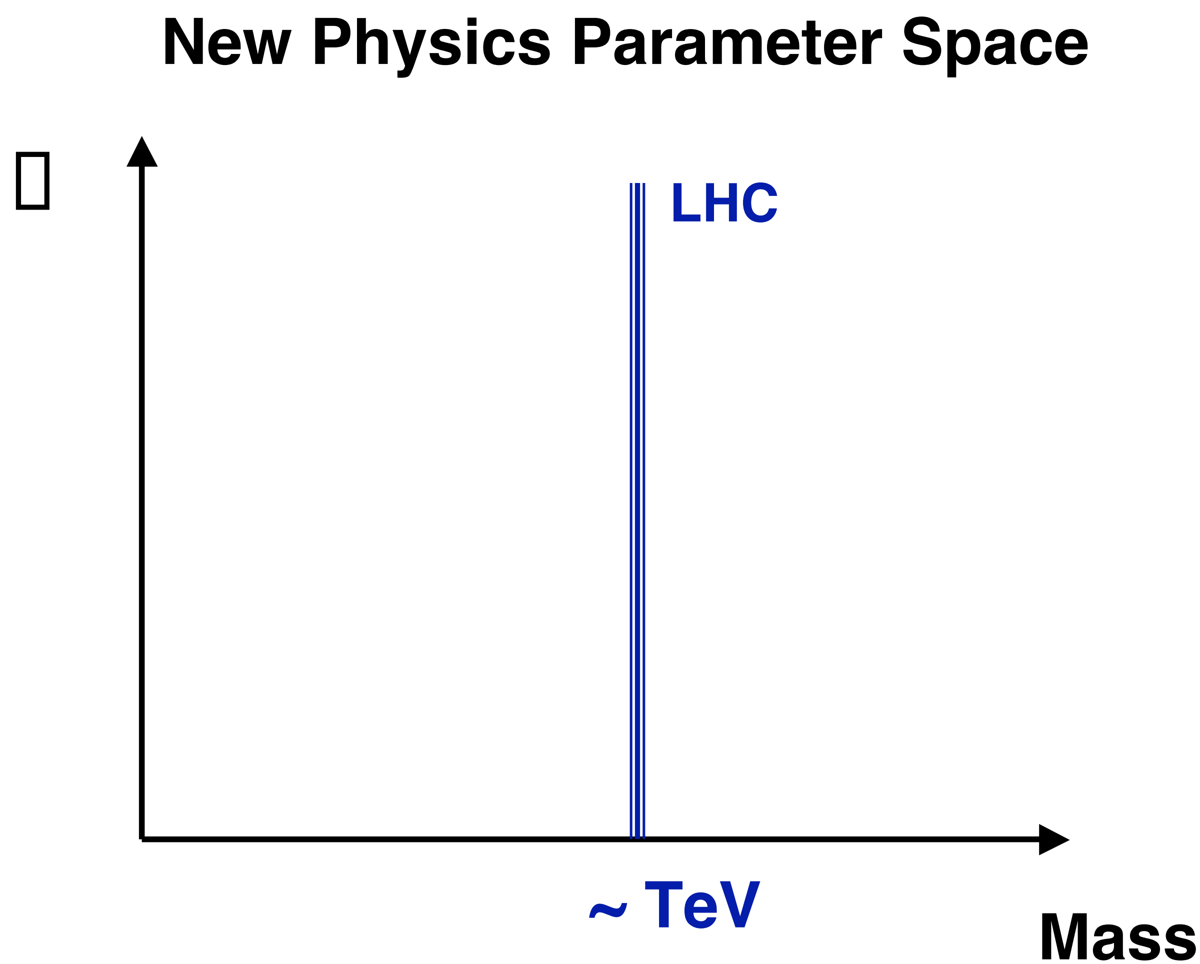

Pictorial Example:

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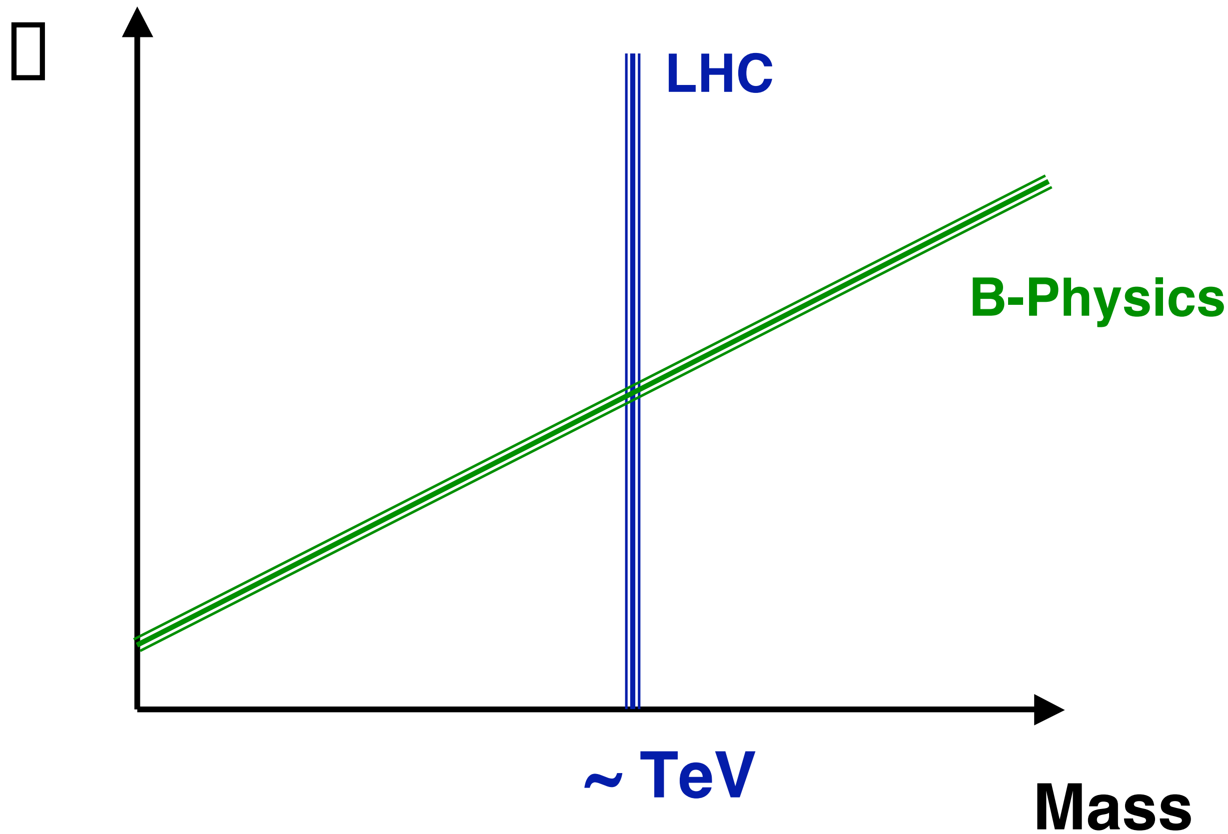

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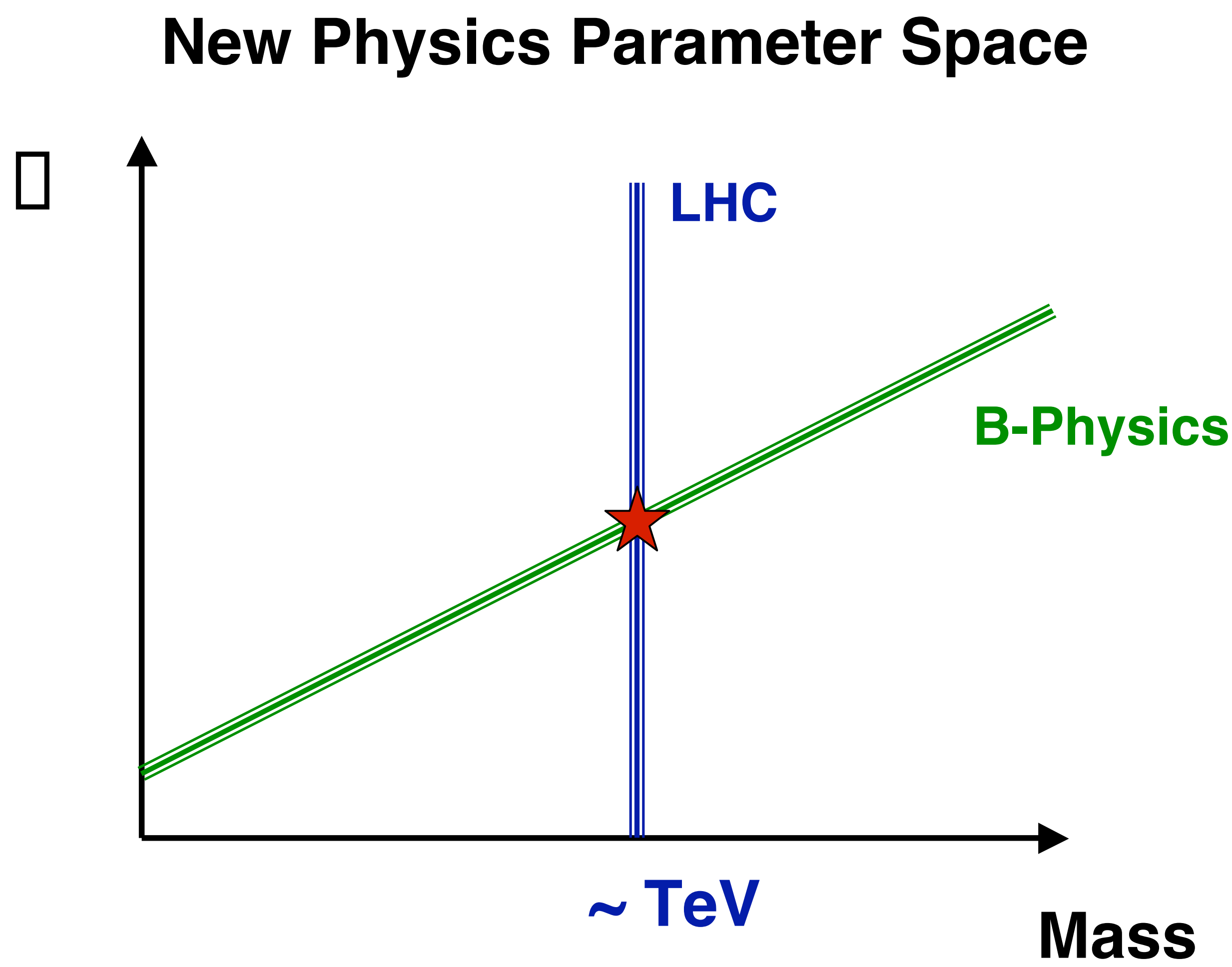


Complementary knowledge from LHC and B Decays!

Concrete Example: Supersymmetry

Once SUSY is discovered, want to determine flavor structure of squark mass matrices

- **Quark Masses – determined by Yukawa couplings**
- **Squark Masses – determined by SUSY breaking terms**
  - **Depends on SUSY breaking mechanism and interactions at the GUT scale probes high scale physics!!**

Diagonal Term: LHC/LC
Off-Diagonal Term: Flavor Physics

$$M_{\tilde{q}}^2 = \begin{pmatrix} m_{11}^2 & m_{12}^2 & m_{13}^2 \\ m_{21}^2 & m_{22}^2 & m_{23}^2 \\ m_{31}^2 & m_{32}^2 & m_{33}^2 \end{pmatrix}$$

Tools for Probing New Physics

- **Consistency among angles & sides of U.T., B_s-Mixing, K physics**
- **Comparison of CP Violation in different channels**

  sin 2□ via B □ □K_s, □K_s, □'K_s, $K^+K^-K_s$

  sin 2□via B_d □ DK, B_s □ D_sK
- **Rare Processes**

  Decays B □ $X_{s/d}$□, $X_{s/d}ll$, l^+l^-, X_s□□$^-$

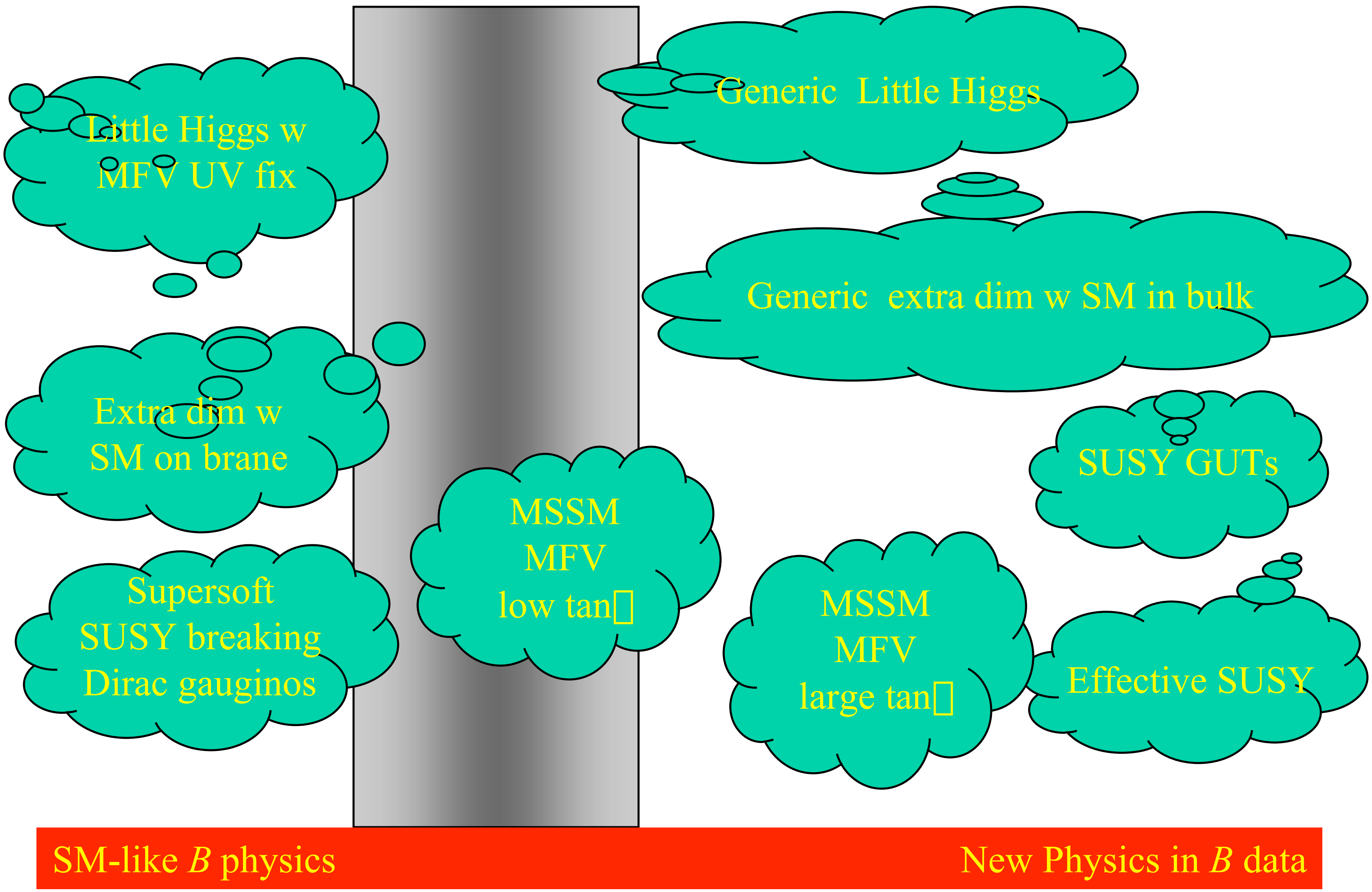
  A_{FB} in B □ X_sll

  CP Asymmetries in B □ $X_{s/d}$□, $X_{s/d}ll$

  D-Mixing

  □□ □□
- **Standard Model Zeros**
- **Patterns of distinguishing New Physics**

Flavor Violation in Models which address the Hierarchy



G. Hiller

Present Heavy Flavor Physics Constraints on New Models: Example 1 - SUSY

C
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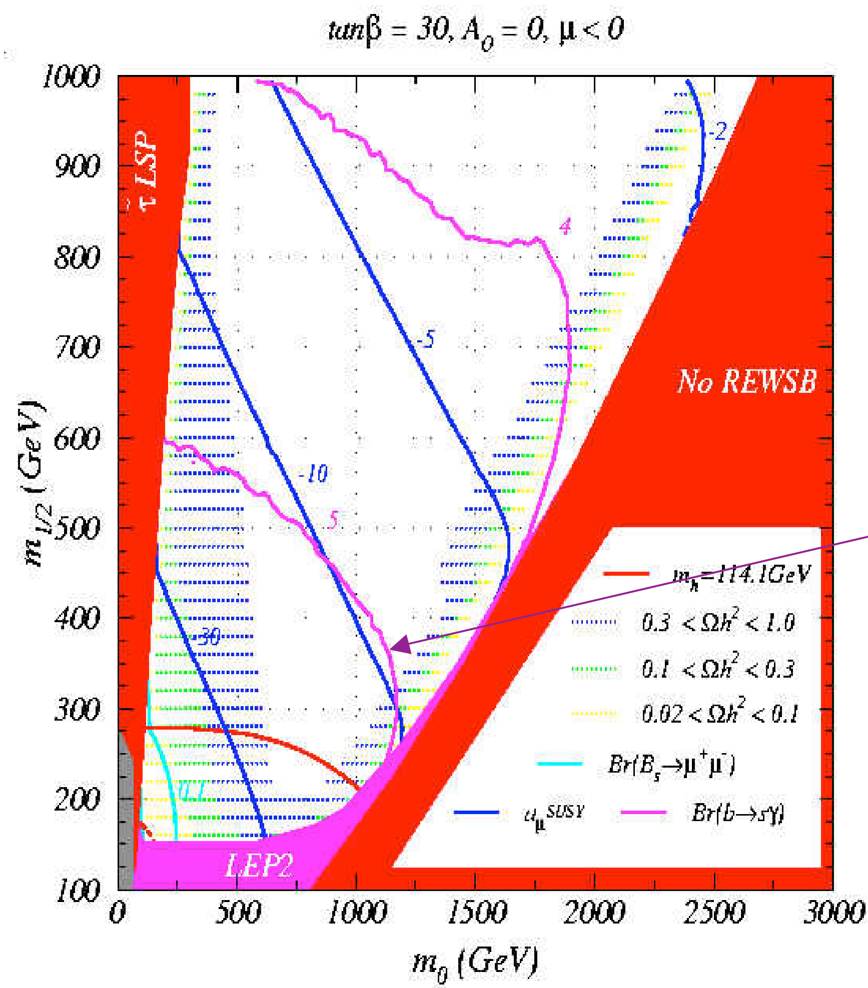
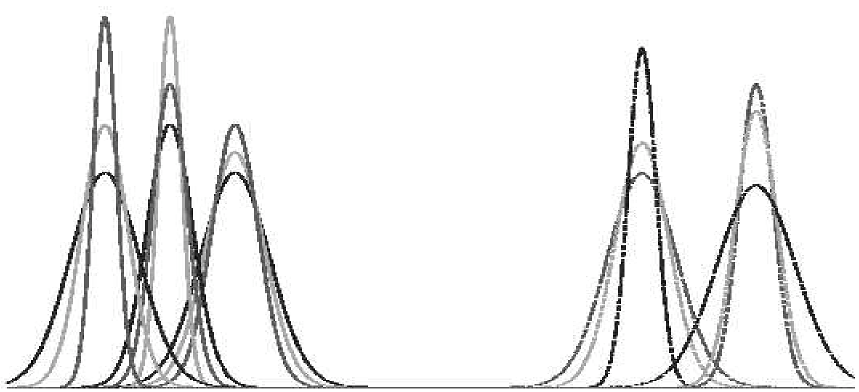


Common Scalar Mass

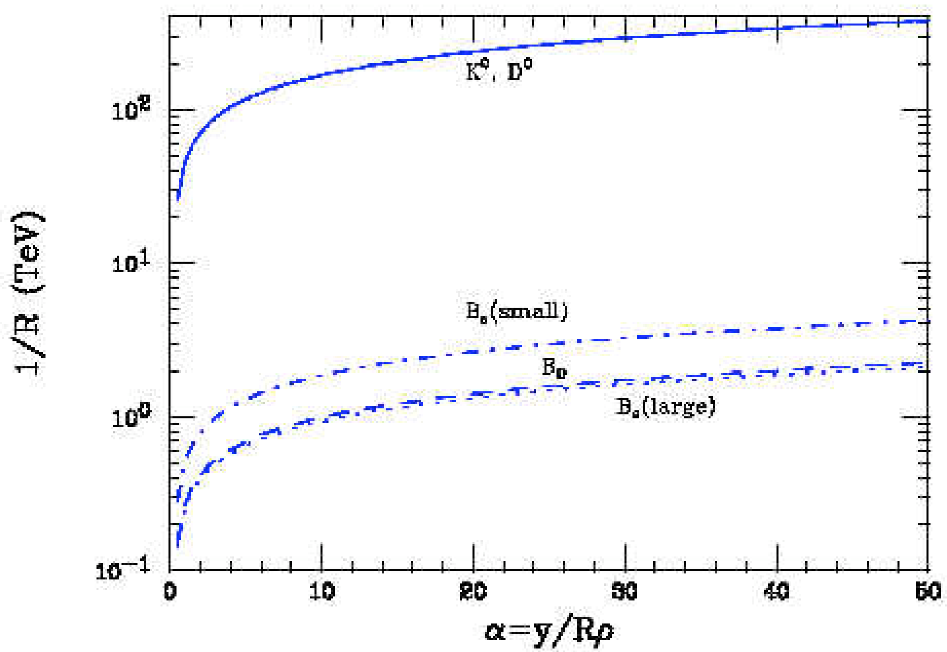
- **Constraints on SUSY 2-d parameter plane**
- **Msugra**
- **Contours of $b \to s\gamma$ in 10^{-4}**

Baer etal. hep-ph/0205325

Example 2: TeV^{-1} Extra Dimensions



Fermions are separated in the bulk



Tree-Level Strong FCNC are generated from gluon KK states

Bounds on size of Xtra-D vs fermion separation from Meson Mixing

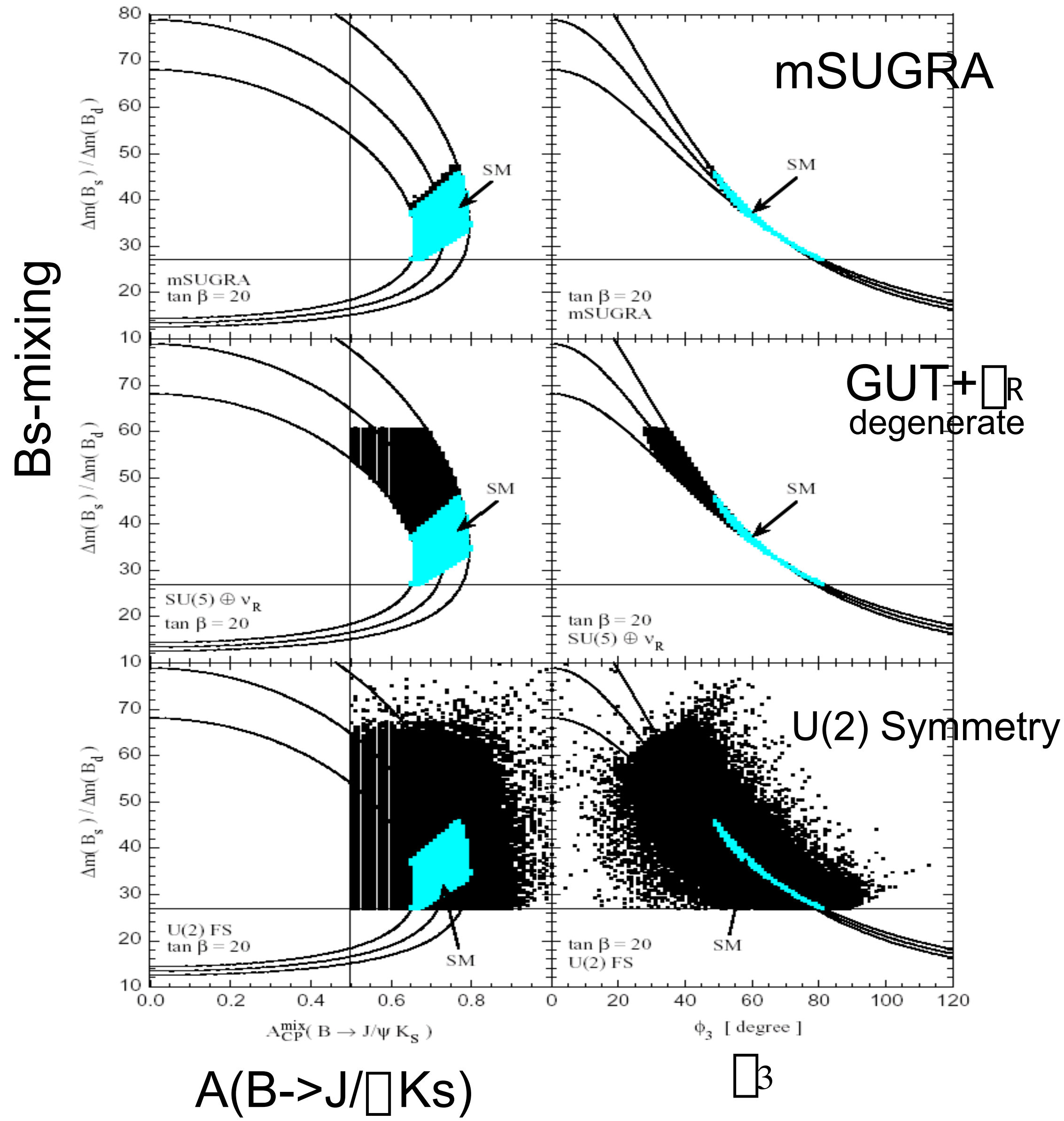
JLH, Lillie hep-ph/0306193

Unitarity Triangle Correlations

1. Minimal SUGRA:
   The deviation from the SM is less than 10%.

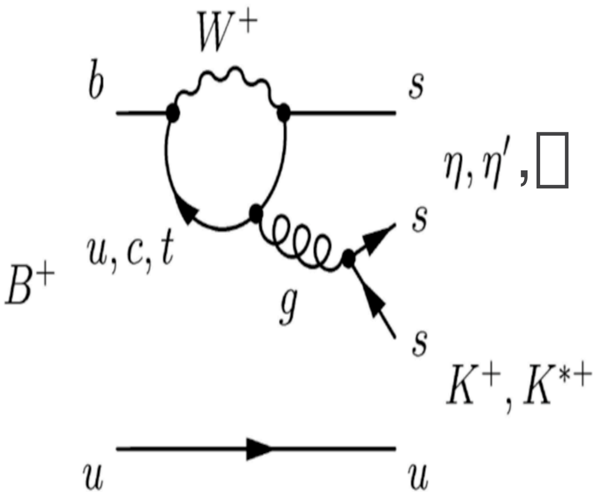
2. SUSY GUT with ν_R:
   degenerate-case
   Bs-mixing can be different from the SM.
   B-unitarity triangle is closed.

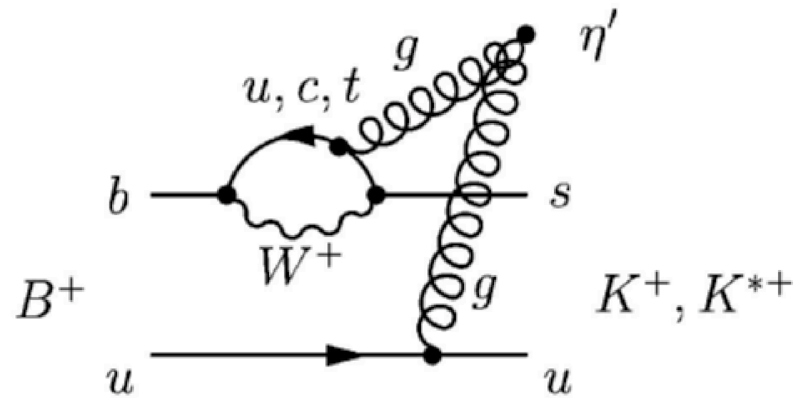
3. U(2) flavor symmetry:
   Large SUSY corr. to K, Bd, and Bs mixings.
   B-unitarity triangle may not be closed.

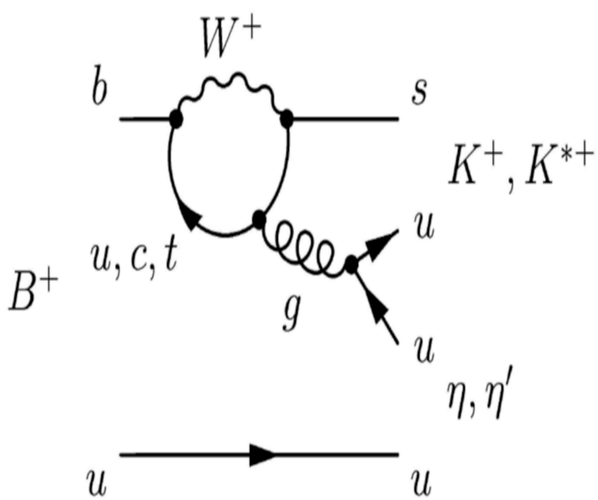


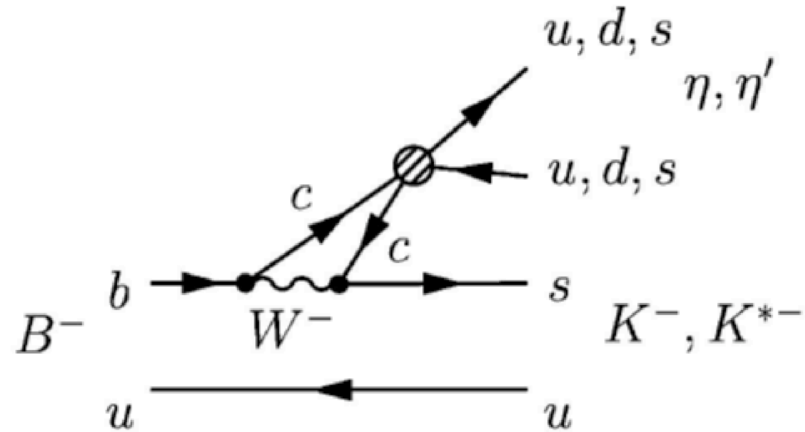
Goto etal

Comparison of Different Channels: sin 2□



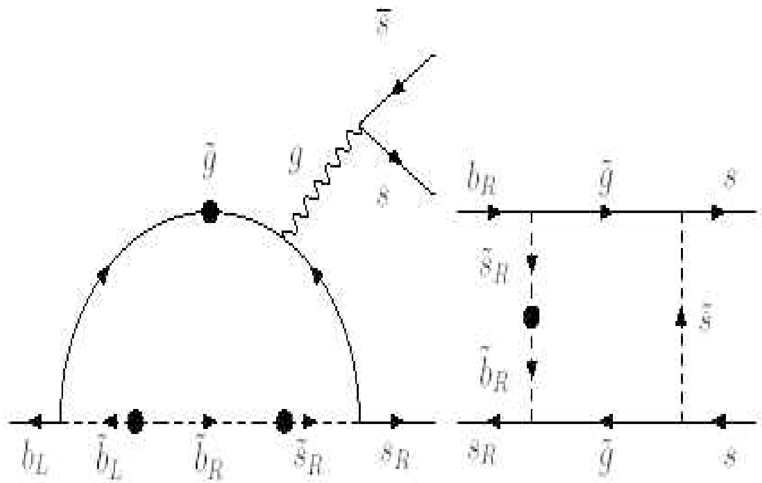






+ Tree-Level contributions to □K_s

Example: Supersymmetry

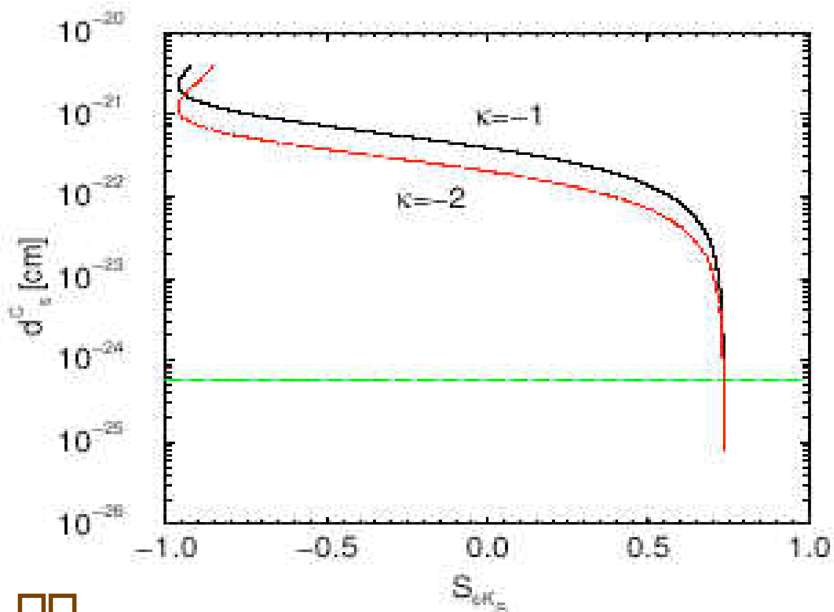


Large $\tilde{s}_R - \tilde{b}_R$ Mixing Contributes to ϕK_s

Similar graph contributes to Nucleon EDMs!

Gluonic Penguin Contribution

Strong Bounds from Hg EDM



Hisano etal hep-ph/0308255

*** Scalar Penguin Bounded by $B_s \to \mu\mu$**

Many CP Asymmetries can be changed by SUSY

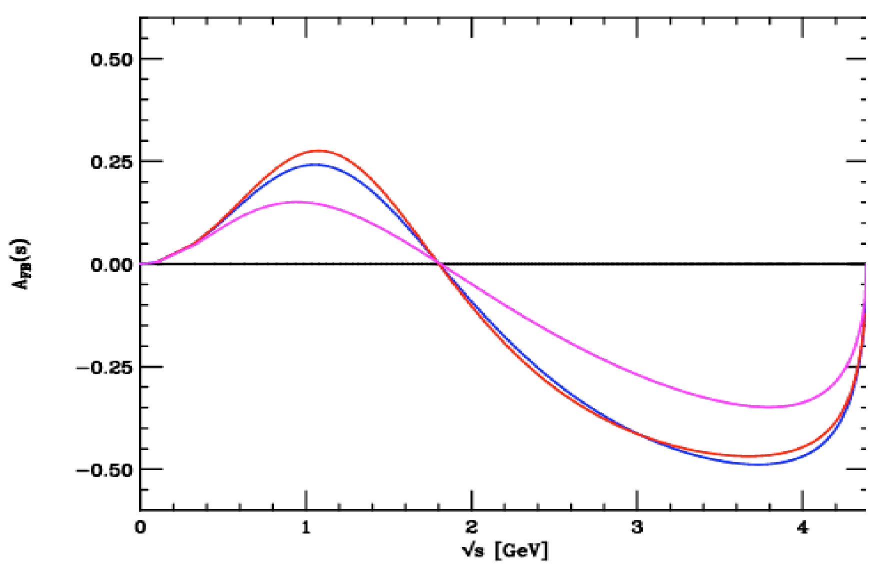
TABLE II. CP phases for B decays. $\phi^D_{\rm SM}$ denotes the decay phase in the SM; for each channel, when two amplitudes with different weak phases are present, one is given in the first row, the other in the last one, and the ratio of the two in the $r_{\rm SM}$ column. $\phi^D_{\rm SUSY}$ denotes the phase of the SUSY amplitude, and the ratio of the SUSY to SM contributions is given in the r_{250} and r_{500} columns for the corresponding SUSY masses.

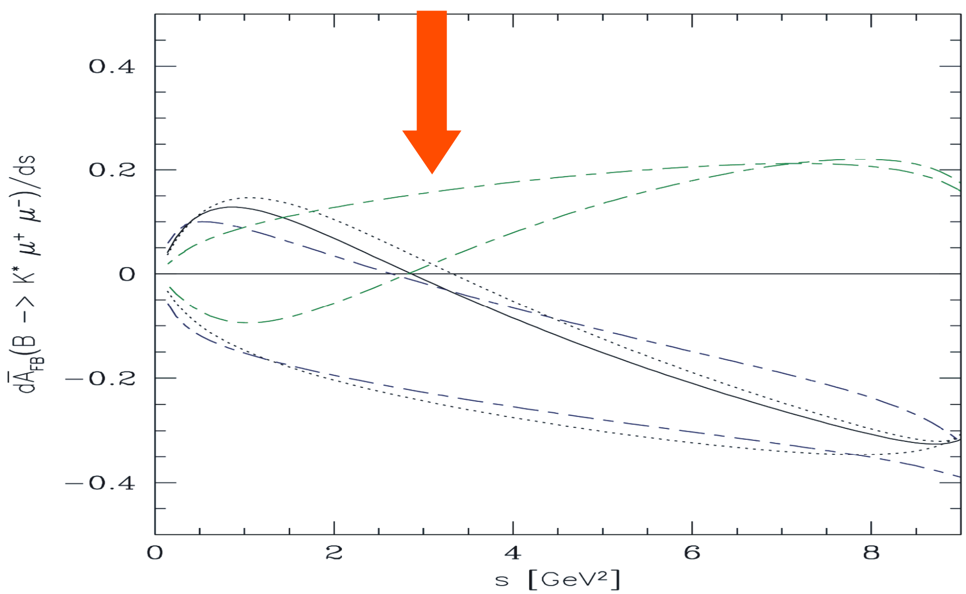
Incl.	Excl.	$\phi^D_{\rm SM}$	□SM [redacted]	$\phi^D_{\rm SUSY}$	□250 [redacted]	□500 [redacted]
$b \to c\bar{c}s$	$B \to J/\psi K_S$	0	–	ϕ_{23}	$0.03 - 0.1$	$0.008 - 0.04$
$b \to s\bar{s}s$	$B \to \phi K_S$	0	–	ϕ_{23}	$0.4 - 0.7$	$0.09 - 0.2$
$b \to u\bar{u}s$		Tree γ				
	$B \to \pi^0 K_S$		$0.009 - 0.08$	ϕ_{23}	$0.4 - 0.7$	$0.09 - 0.2$
$b \to d\bar{d}s$		Penguin 0				
$b \to c\bar{u}d$		0				
	$B \to D^0_{CP}\pi^0$		0.02	–	–	–
$b \to u\bar{c}d$		γ				
	$B \to D^+D^-$	Tree 0	$0.03 - 0.3$		$0.007 - 0.02$	$0.002 - 0.006$
$b \to c\bar{c}d$				ϕ_{13}		
	$B \to J/\psi\pi^0$	Penguin β	$0.04 - 0.3$		$0.007 - 0.03$	$0.002 - 0.008$
	$B \to \phi\pi^0$	Penguin β	–		$0.06 - 0.1$	$0.01 - 0.03$
$b \to s\bar{s}d$				ϕ_{13}		
	$B \to K^0\overline{K}^0$	u-Penguin γ	$0 - 0.07$		$0.08 - 0.2$	$0.02 - 0.06$
$b \to u\bar{u}d$	$B \to \pi^+\pi^-$	Tree γ	$0.09 - 0.9$	ϕ_{13}	$0.02 - 0.8$	$0.005 - 0.2$
$b \to d\bar{d}d$	$B \to \pi^0\pi^0$	Penguin β	$0.6 - 6$	ϕ_{13}	$0.06 - 0.4$	$0.02 - 0.1$
	$B \to K^+K^-$	Tree γ	$0.2 - 0.4$		$0.04 - 0.1$	$0.01 - 0.03$
$b\bar{d} \to q\bar{q}$				ϕ_{13}		
	$B \to D^0\overline{D}^0$	Penguin β	only β		$0.01 - 0.03$	$0.003 - 0.006$

Ciuchini, Franco, Martinelli, Masiero, & Silvestrini

Kinematic Distributions and CP Asymmetries in Rare Decays

In SUGRA, sign of C_7 determines sign of A_{FB}





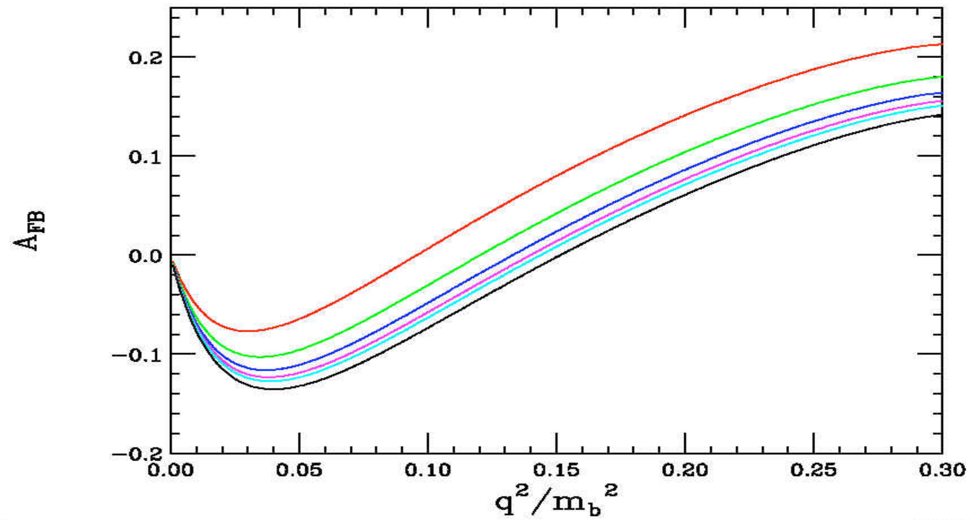
Bauer, Stech & Wirbel
Ball and Braun
Melihov, Nikitin and Simula

SM, ·····> SUGRA with $\pm C_7$,
MIA with suppressed Br, MIA with enhanced Br

Standard Model predictions are robust!

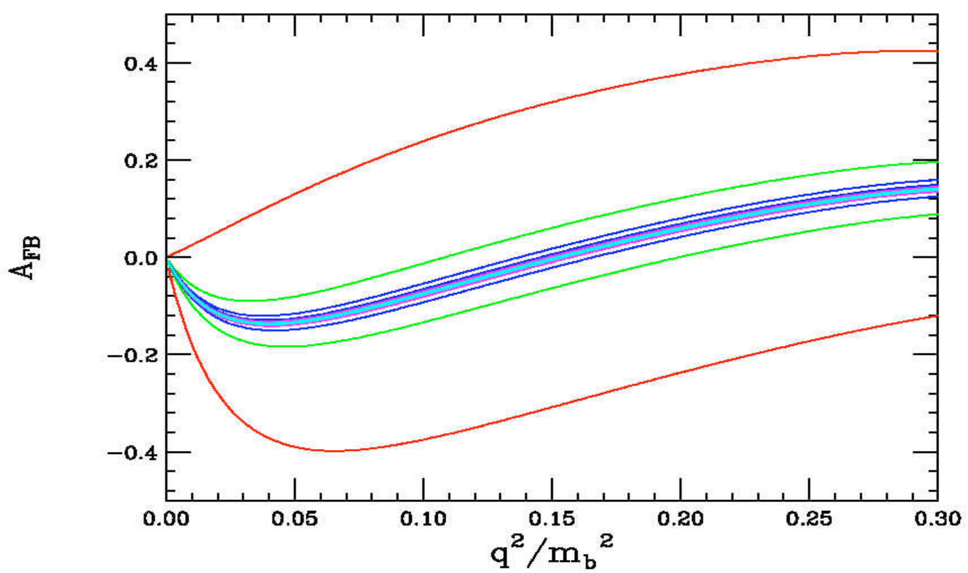
Ali, *et al.*

Graviton Penguins in B $X_s ll$



Randall-Sundrum Model

M_1 = 600 – 1000 TeV



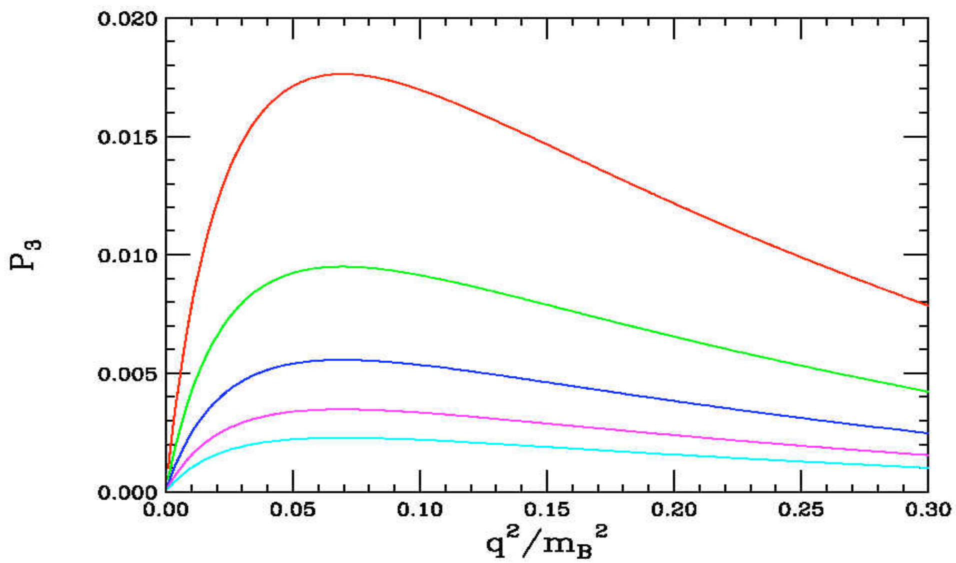
Large Extra Dimensions

M_D = 1 – 2.5 TeV

Probes the TeV scale!

T. Rizzo

Moments of the Angular Distribution in $B \to X_s ll$



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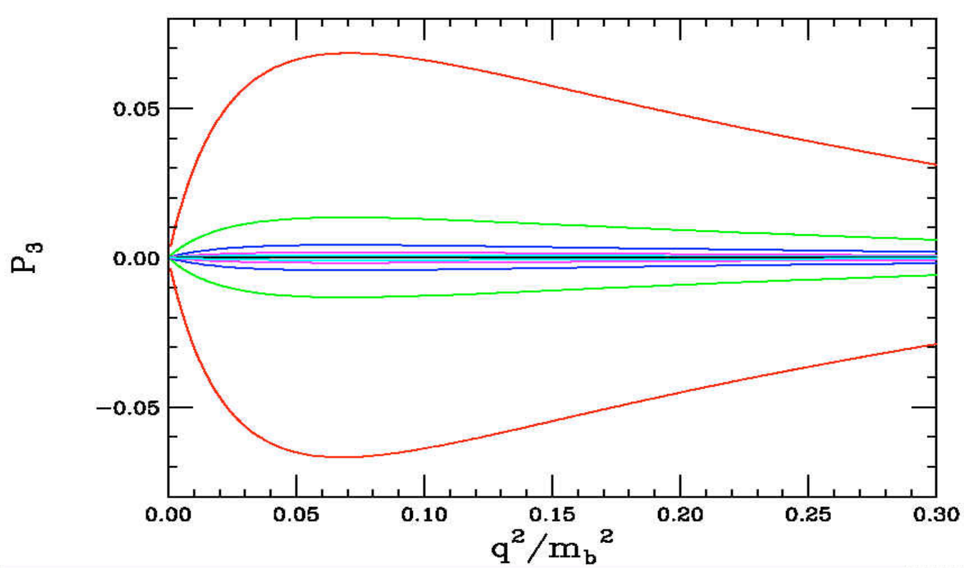


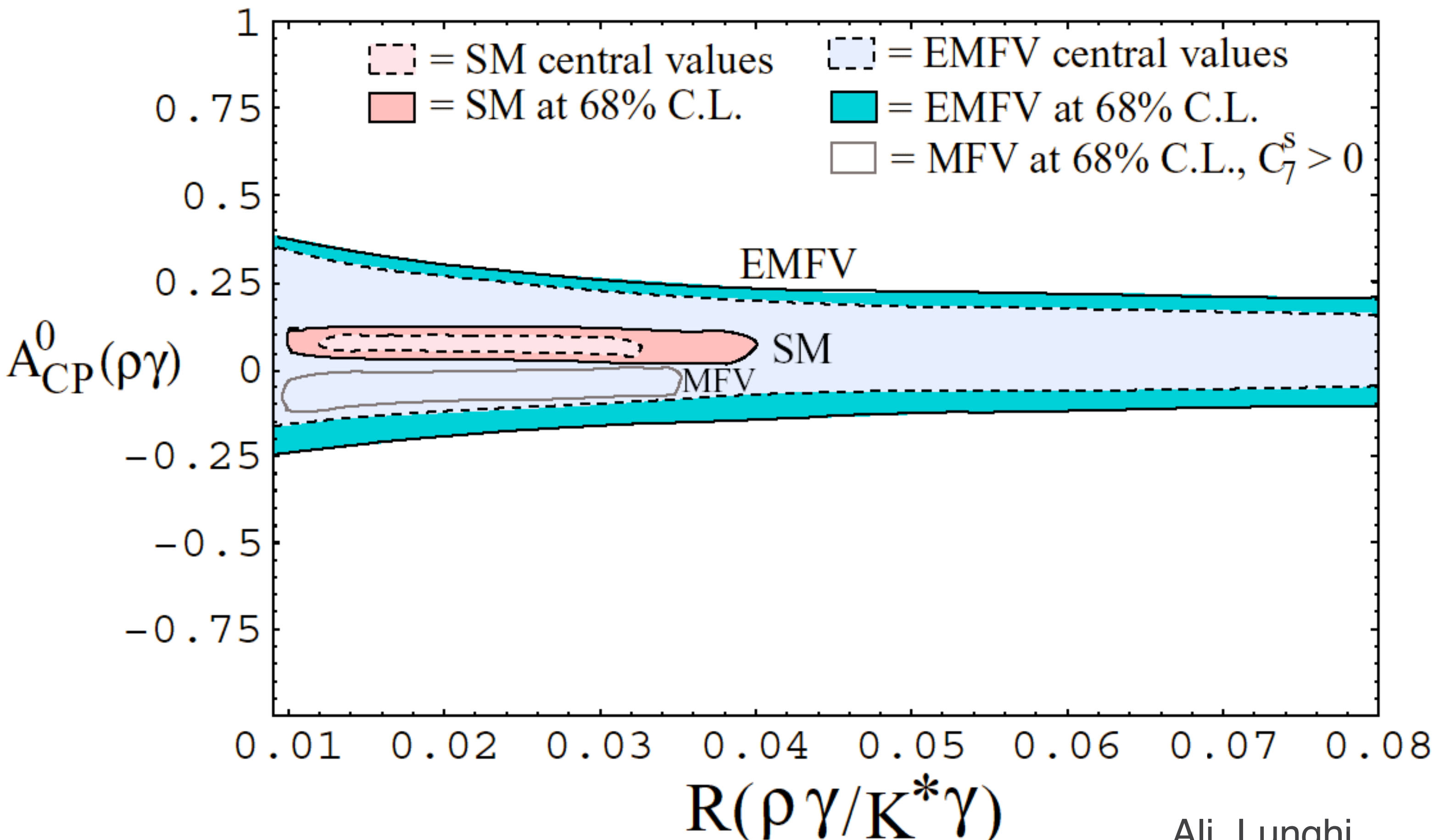
Large Extra Dimensions

M_D = 1 – 2.5 TeV

Uniquely determines spin-2 Exchange!

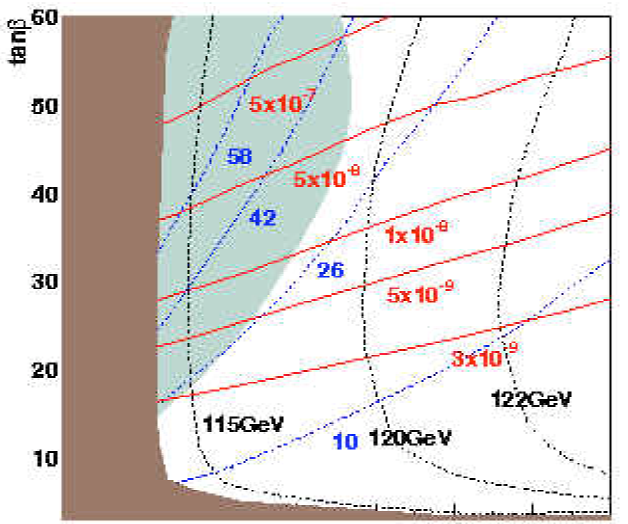
T. Rizzo

Direct CP Asymmetries in Rare Decays

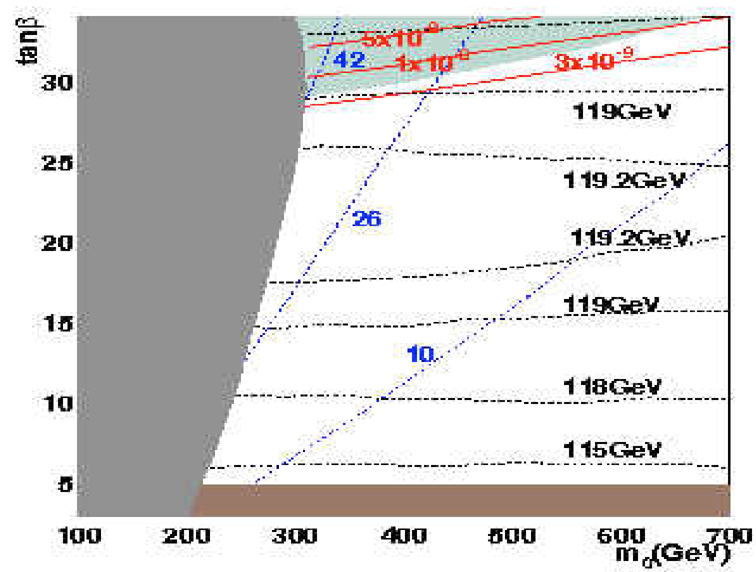


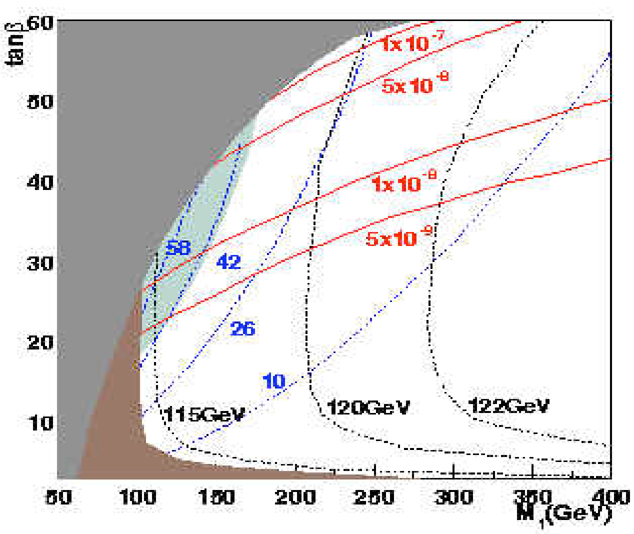
Ali, Lunghi

Patterns Distinguish SUSY Breaking Mechanisms



MSugra





GMSB

AMSB

$B_s \to \mu\mu$, $B \to X_s\gamma$, m_h

Baek, Ko, Song, hep-ph/0208112

Patterns Distinguish Between Models

Model	CP Violation: B_d^0–$\overline{B}_d^0$ Mixing	CP Violation: Decay Ampl.	Rare Decays	D^0–$\overline{D}^0$ Mixing
MSSM	$\mathcal{O}(20\%)$ SM Same Phase	No Effect	$B \to X_s \gamma$ – yes $B \to X_s\, l^+ l^-$ – no	No Effect
SUSY – Alignment	$\mathcal{O}(20\%)$ SM New Phases	$\mathcal{O}(1)$	Small Effect	Big Effect
SUSY – Approx. Universality	$\mathcal{O}(20\%)$ SM New Phases	$\mathcal{O}(1)$	No Effect	No Effect
R-Parity Violation	Can Do	Everything	Except Make	Coffee
MHDM 2HDM	$\sim$ SM/New Phases $\sim$ SM/Same Phase	Suppressed Suppressed	$B \to X_s \gamma$, $B \to X_s \tau\tau$ $B \to X_s \gamma$	Big Effect No Effect
Quark Singlets Fourth Generation	Yes/New Phases $\sim$ SM/New Phases	Yes Yes	Saturates Limits Saturates Limits	$Q = 2/3$ Big Effect
LRM – $V_L = V_R$ – $V_L \neq V_R$	No Effect Big/New Phases	No Effect Yes	$B \to X_s \gamma$, $B \to X_s\, l^+ l^-$ $B \to X_s \gamma$, $B \to X_s\, l^+ l^-$	No Effect No Effect
DEWSB	Big/Same Phase	No Effect	$B \to X_s \ell\ell$, $B \to X - s\nu\overline{\nu}$	Big Effect

JLH, BaBar Physics Book

Conclusions: Heavy Flavor Physics

- Lots of excitement!
- Provides complementary info to LHC
- Probes Flavor Structure of New Physics
- Patterns distinguish models of New Physics

Look forward to exciting times ahead!!

NASA satellites spy hidden penguin `oases’

NASA (news - web sites) satellites have helped scientists learn about the hard-to-find Antarctic Ocean 'oases' where penguins feast and thrive, researchers said on October 7, 2003.

-YaHoo Top News Story
8 October, 2003